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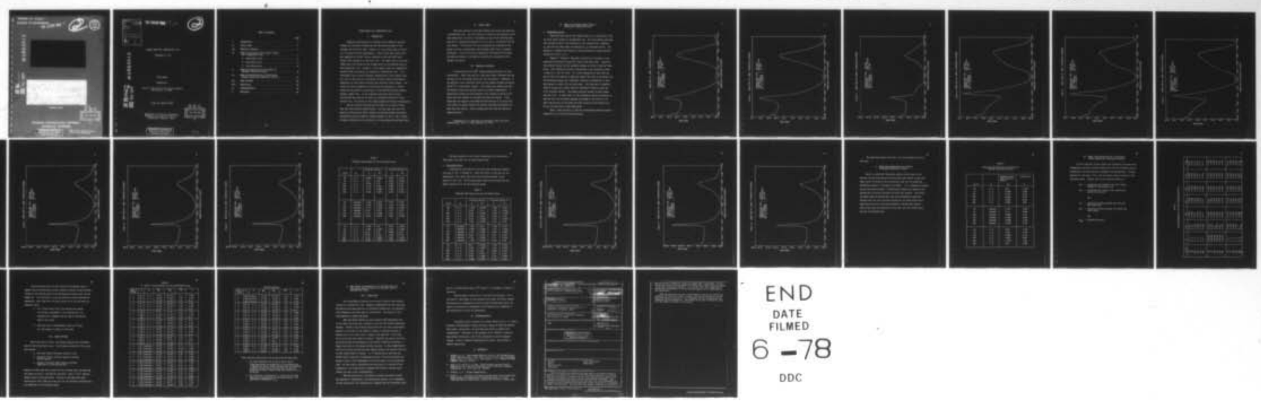

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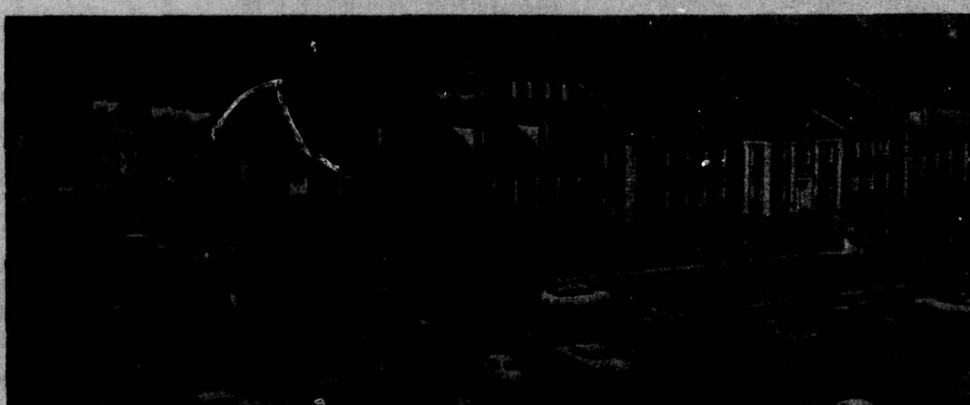

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DIPOLE ARRAY ON A TRANSMISSION LINE

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Final Report

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DIPOLE ARRAY ON A TRANSMISSION LINE

I. INTRODUCTION

Radiation characteristics of antenna arrays depend on spacings between the individual antennas and the amplitude and phase of the voltages fed to each of them. However, it is not always easy or practical to satisfy the feed requirements. Several years ago a novel array was suggested by Sletten[1] and was analyzed by Chen and King[2] where dipoles were coupled to an open-wire line. The dipoles were a half-wave length apart and located on the voltage maxima of the standing waves on the transmission line. Recently, a much simpler scheme was suggested by Sletten[3] where the dipoles are located on a transmission line. It is conceivable that a certain radiation characteristic of the dipole array, e.g. gain in the end-fire or broadside direction could be optimized by adjusting the inter-dipole distances and individual dipole lengths. The latter and recent suggestions from Sletten was explored to a limited extent by the author as a participant in the USAF-ASEE Faculty Research Program, Summer 1976. In this computer aided study end-fire gain calculations were made for an array of two dipoles placed on a transmission line. The results of this study prompted the present investigation.

The end-fire gain calculations were made for an array of three, four and five uniformly spaced dipoles. The array gain was then maximized by optimizing the dipole lengths and spacings between the dipoles. Calculations were also made for antenna patterns in the E- and H- planes to obtain information on the location of the main beam and the beam width.

II. DIPOLE ARRAY

The array consists of half-wave dipoles each fed at the center by a transmission line. The first dipole is located at the generator end of the transmission line which is terminated in one of the following ways: open (O.C.), matched, and shorted (S.C.) at a point $\lambda/8$ further from the last dipole. The choice of the last termination was prompted by the manner in which a log-periodic dipole antenna (LPD) array is commonly terminated. Like an LPD array an additional 180^{o} phase shift between the adjacent dipoles is provided by switching the transmission line between the dipoles.

III. NUMERICAL PROCEDURE

It was planned to use AMP* (Antenna Modeling Program) for gain calculations. Check runs made for a half-wave dipole indicated that the accuracy of the calculated results was not satisfactory. Therefore, it was decided to use a modified version of the computer program written by Drane[4] for a log-periodic antenna. This program was changed such that the dipoles lengths and spacings could be assigned independently. A maximization program was then coupled to this program to optimize the array gain with respect to the dipole spacings and lengths. It was found that the computer time needed for maximization of the array gain with respect to dipole lengths and spacings increased considerably for more than five dipoles. Drane's program was also used for obtaining antenna patterns.

*Prepared by M. B. Associates of California under the joint sponsorship of the U. S. Army, Navy and Air Force.

IV. ARRAY OF HALF-WAVE DIPOLES EQUALLY SPACED ON A TRANSMISSION LINE

A. Three-dipole Array

Three half-wave dipoles were spaced equally on a transmission line; the first being located at the generator end. Gain calculations were made with selected values of the transmission line characteristic impedance, Z_C, and with the three types of terminations Z_T, mentioned earlier. The distance, d, between the dipoles was varied between the closest possible distance of 0.016 λ to 1 λ.

Figures 1 through 6 show gain variations as a function of the normalized interdipole distance for some of the above cases. Generally, two principal maxima and one secondary maximum are found in each of these cases. The interdipole distance corresponding to the secondary maximum is about 0.5 λ for all cases. It is also interesting to note that the gain at the first maximum is generally higher than that at the second, and the difference between the interdipole distances corresponding to these gain maxima is around 0.52 λ for most cases. The array gain is generally found to change very rapidly with the interdipole distance around the first principal maximum. The second principal maximum is much broader than the first. It means that, if the interdipole spacing corresponds to that for the first principal maximum, the length of the array will be small and the gain will be high; but exact location of the dipoles will be very critical and at times impractical.

Table 1 shows the gain, G, and the corresponding normalized dipole separation d/λ at the two principal maxima.

Figure 1. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

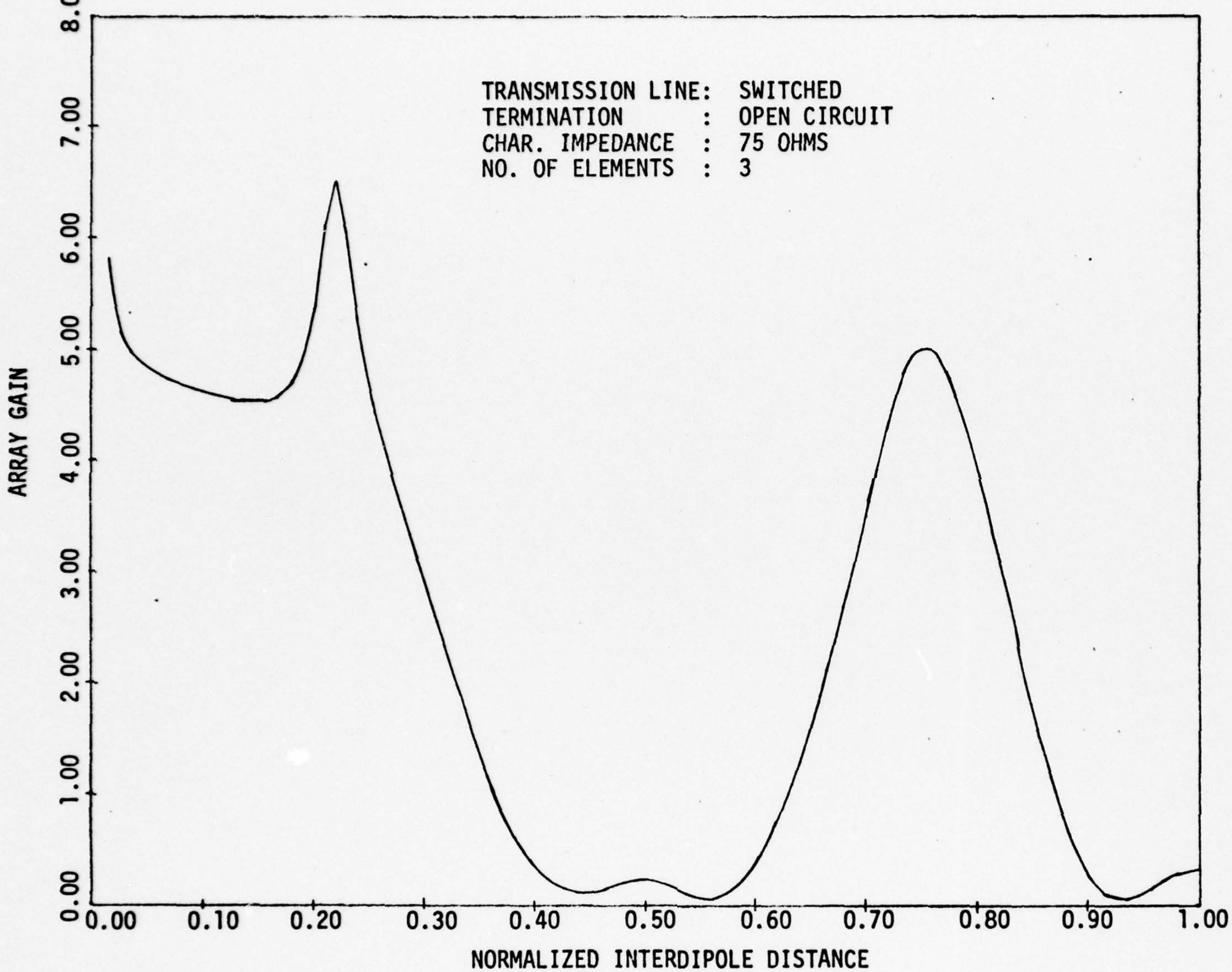


Figure 2. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

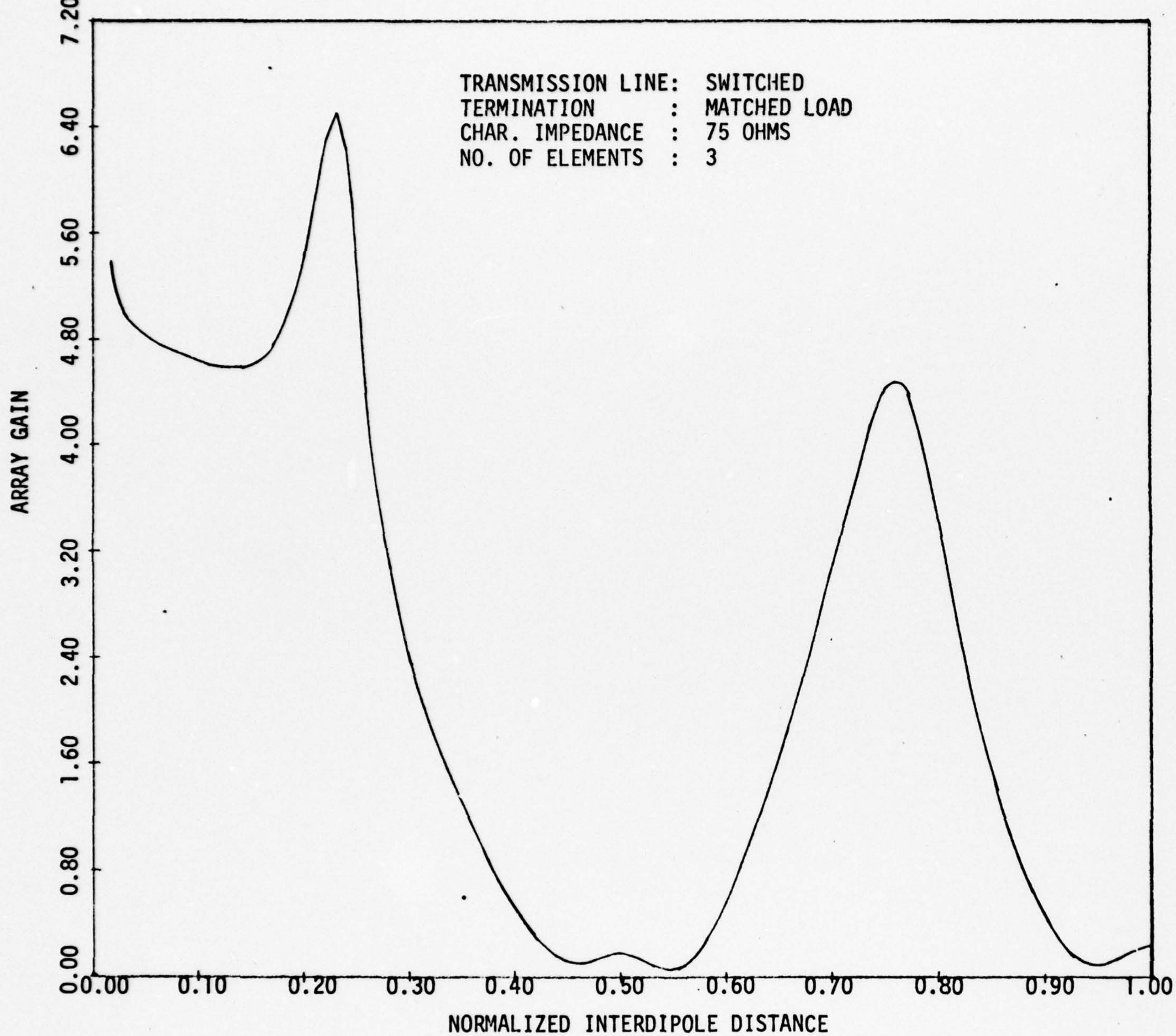


Figure 3. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

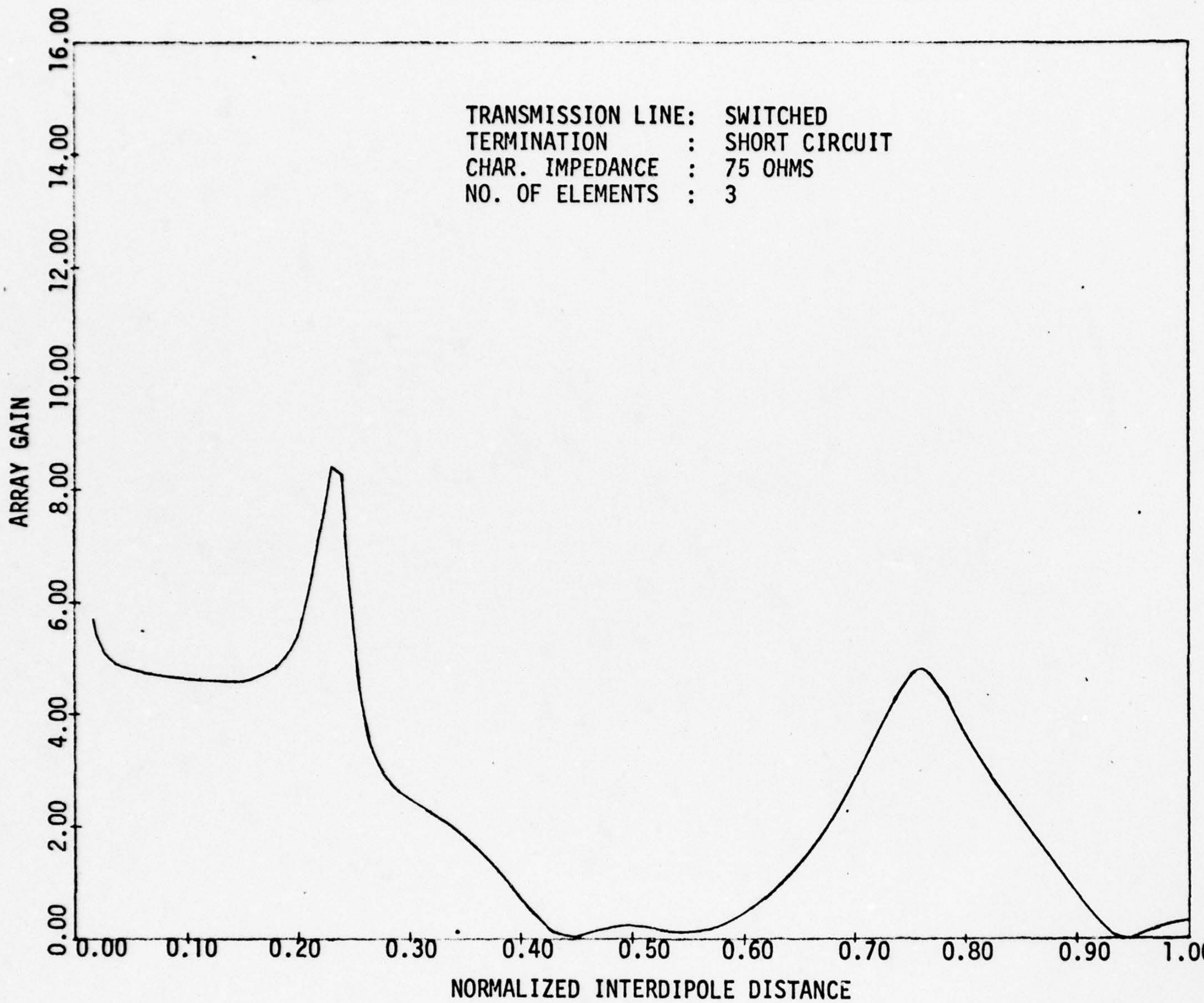


Figure 4. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

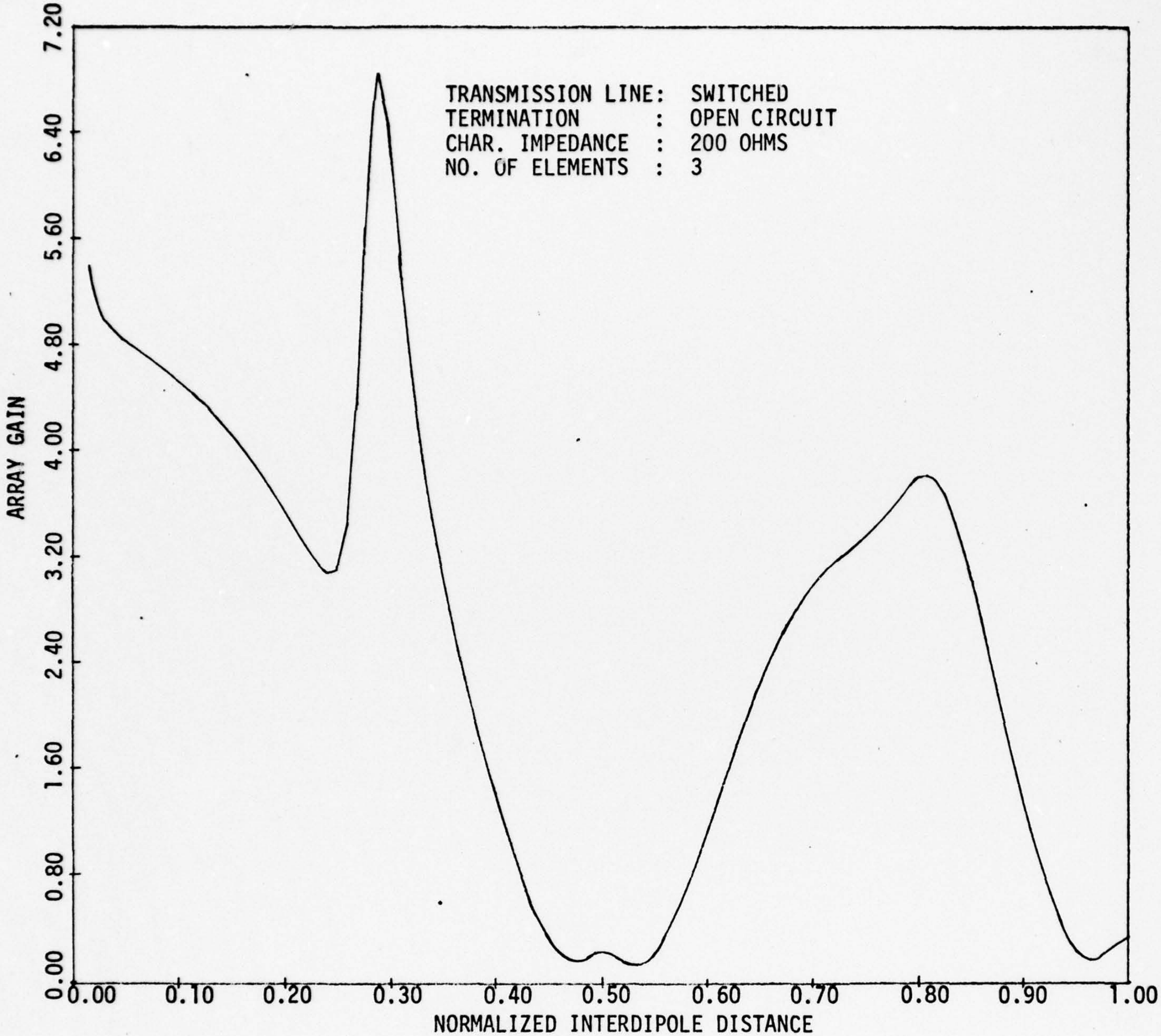


Figure 5. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

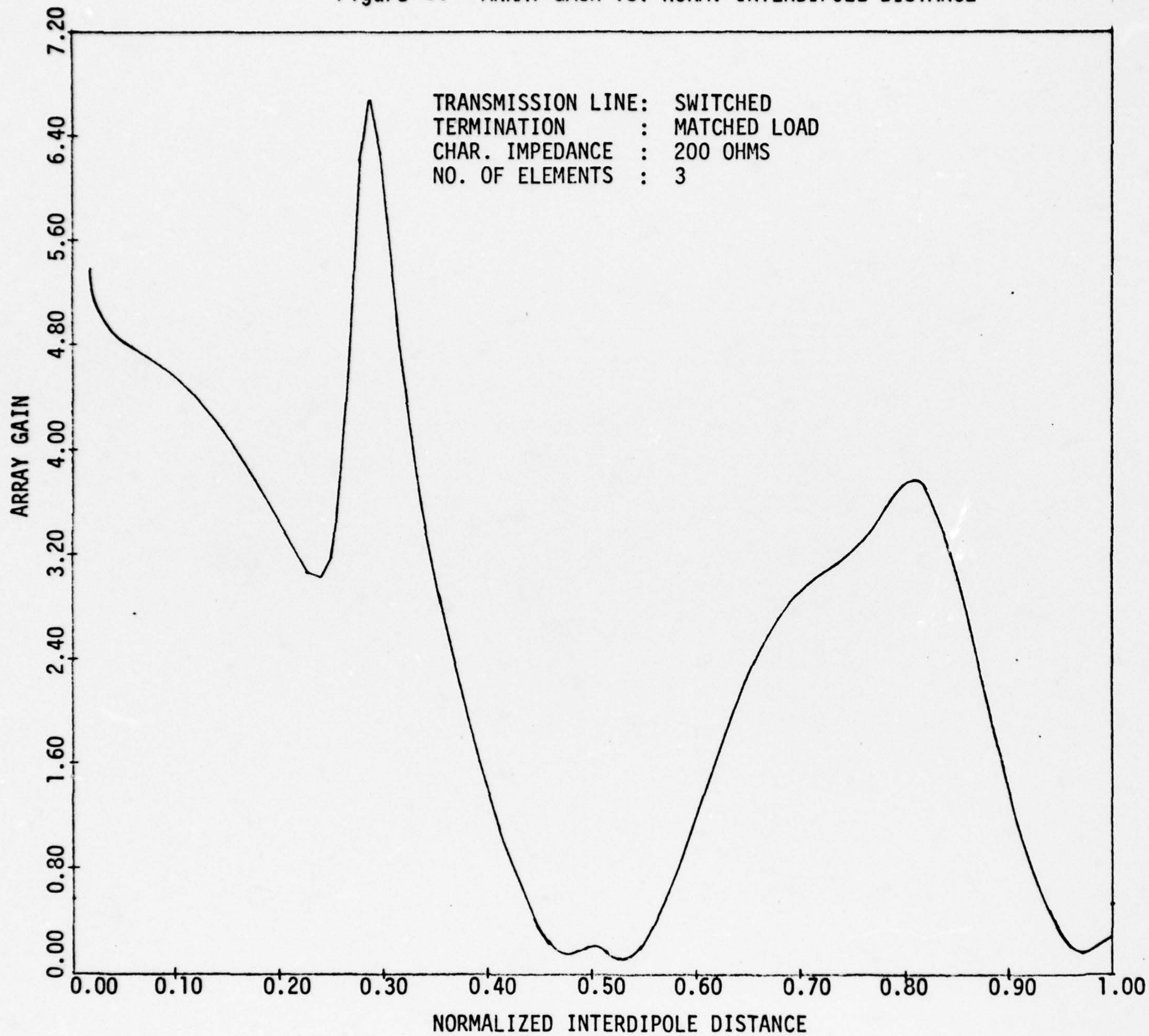


Figure 6. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

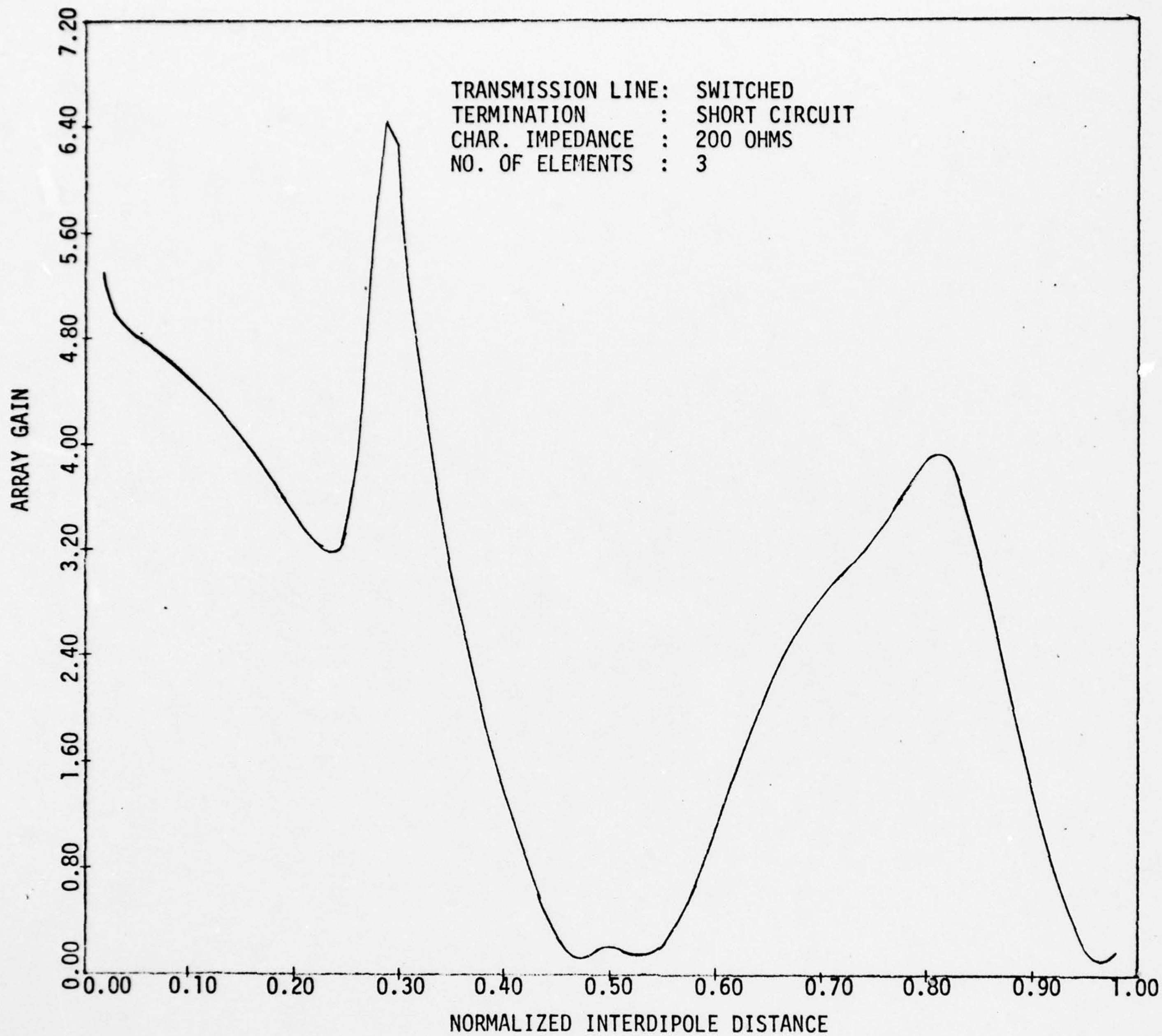


Table 1

Principal Maxima for the Three-Dipole Array

		Principal Maxima I		Principal Maxima II	
Z_C (Ω)	Z_T	G	d/λ	G	d/λ
50	O. C.	3.718	0.221	4.699	0.7435
75	O. C.	6.506	0.221	5.012	0.753
100	O. C.	8.298	0.24	4.958	0.7625
125	O. C.	8.626	0.259	4.692	0.772
150	O. C.	8.296	0.2685	4.362	0.7815
200	O. C.	6.882	0.2875	3.821	0.81
50	matched	4.461	0.1925	3.865	0.753
75	matched	6.509	0.2305	4.489	0.7625
100	matched	7.736	0.2495	4.59	0.772
125	matched	8.09	0.259	4.429	0.7815
150	matched	7.733	0.2685	4.187	0.791
200	matched	6.687	0.2875	3.77	0.81
50	S. C.	7.063	0.2115	4.316	0.753
75	S. C.	8.434	0.2305	4.807	0.7625
100	S. C.	9.232	0.2495	4.866	0.772
125	S. C.	8.735	0.259	4.678	0.7815
150	S. C.	7.863	0.2685	4.410	0.791
200	S. C.	6.469	0.2875	3.933	0.81

The following observations can be made from the above table of data:

1. For each value of Z_C the dipole separation corresponding to the two principal maxima appears to be more or less independent of the type of termination.

2. For each type of termination the gain at the two maxima varies with Z_C and attains the highest value for Z_C around 125 ohms.

3. Dipole separation corresponding to each of the two principal maxima increases monotonically with Z_C.

4. In general, the gain at the first principal maximum is higher than that at the second.

B. Four-dipole Array

Figures 7 through 9 show the array gain variation with dipole separation for some cases. In contrast to the situation with three-dipole array, a null replaces the small secondary maximum around $d/\lambda = 0.5\lambda$. Other observations about the three-dipole array are generally true for the four-dipole array. Table 2 gives the principal gain maxima and the corresponding interdipole distance for the four-dipole array.

Figure 7. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

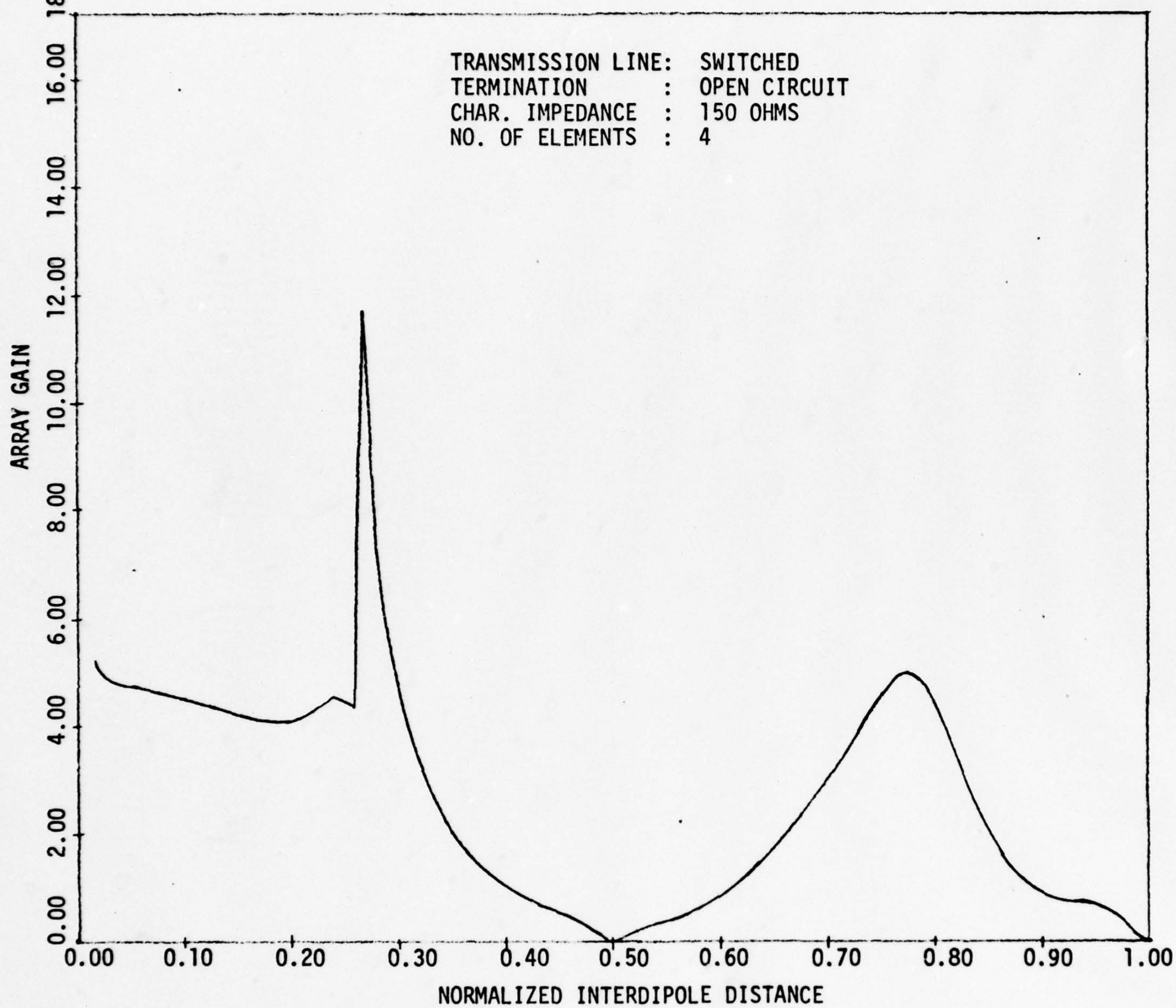


Figure 8.   ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

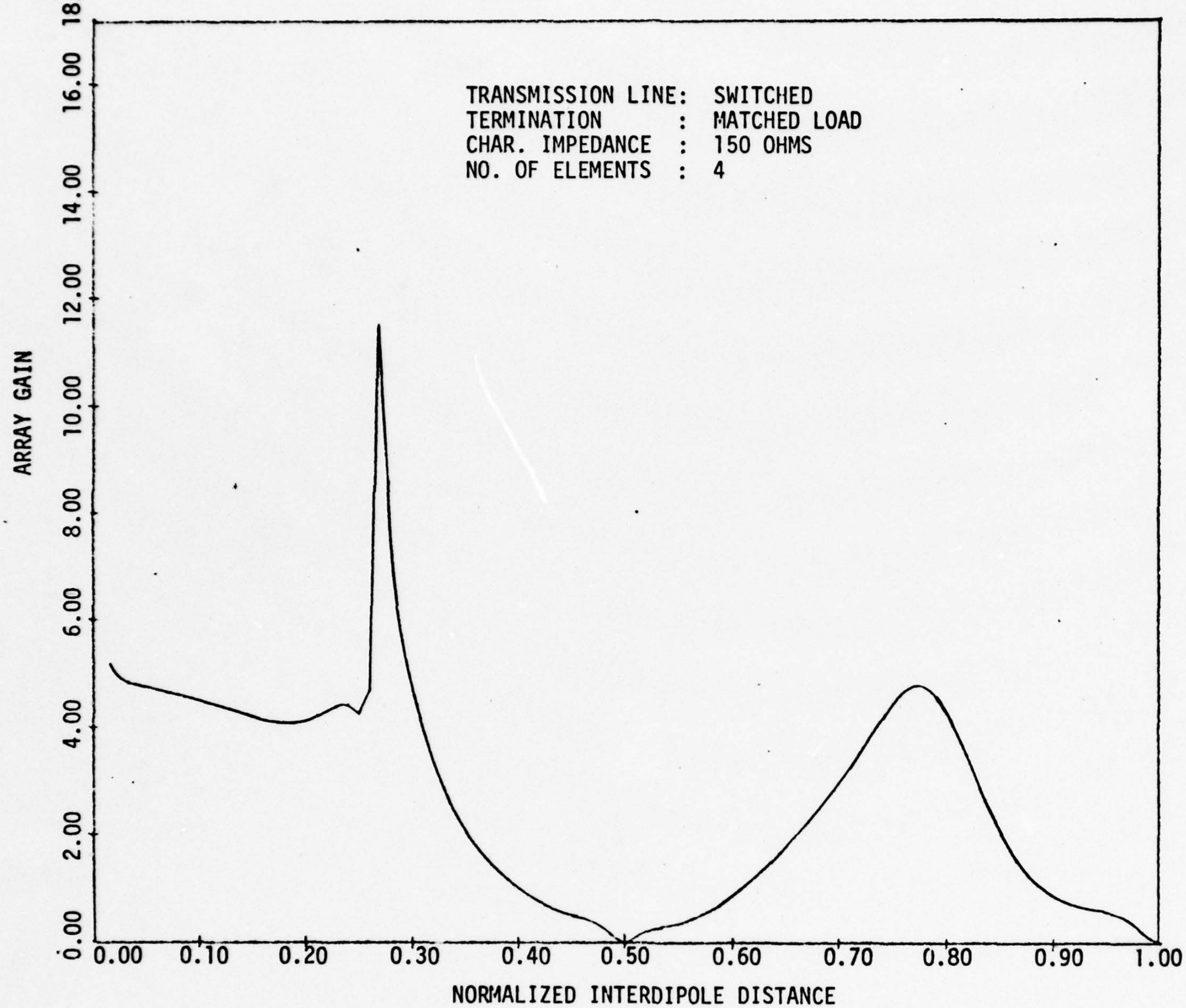


Figure 9. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

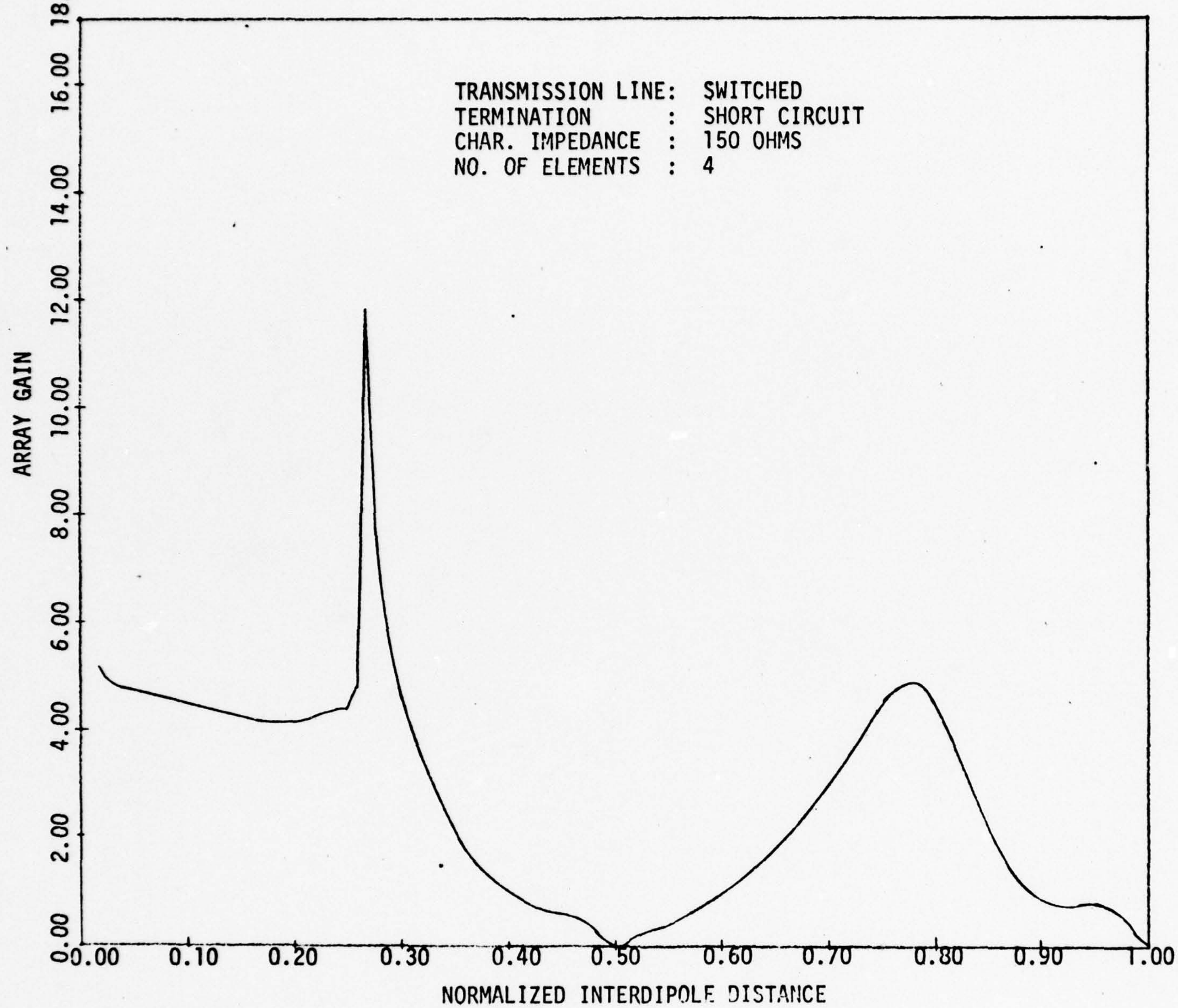


Table 2

Principal Gain Maxima for the Four-Dipole Array

$Z_C(\Omega)$	Z_T	Principal Maxima I		Principal Maxima II	
		G	d/λ	G	d/λ
50	O. C.	6.696	0.2328	6.393	0.753
75	O. C.	8.0	0.24	6.651	0.7625
100	O. C.	10.36	0.24	6.022	0.753
125	O. C.	11.25	0.259	5.586	0.772
150	O. C.	11.71	0.2685	4.946	0.772
200	O. C.	8.707	0.2875	3.982	0.7815
50	matched	4.924	0.2375	5.726	0.753
75	matched	7.523	0.2305	6.145	0.7625
100	matched	9.715	0.2495	5.896	0.7625
125	matched	11.83	0.259	5.37	0.772
150	matched	11.49	0.2685	4.813	0.772
200	matched	8.678	0.2875	3.922	0.7815
50	S. C.	6.929	0.24	6.347	0.7625
75	S. C.	9.944	0.2275	6.451	0.7625
100	S. C.	10.75	0.24	6.058	0.772
125	S. C.	12.08	0.259	5.483	0.772
150	S. C.	11.82	0.2685	4.872	0.7815
200	S. C.	8.393	0.2875	3.926	0.7815

The data presented in this table corroborates with the observations made on the data for the three-dipole array.

C. Five-dipole Array

A few typical variations of array gain with interdipole distance are shown in Fig. 10 through 12. These are similar to the ones for the three-dipole array except that the first principal maximum is much sharper in this case. The following table shows the array gain and the dipole separation for the two principal maxima.

Table 3

Principal Gain Maxima for the Five-Dipole Array

$Z_C(\Omega)$	Z_T	Principal Maxima I		Principal Maxima II	
		G	d/λ	G	d/λ
50	O. C.	6.726	0.2305	7.935	0.753
75	O. C.	10.49	0.24	7.795	0.7625
100	O. C.	12.66	0.2495	6.962	0.7625
125	O. C.	12.97	0.259	6.015	0.772
150	O. C.	12.92	0.2685	5.176	0.7815
200	O. C.	9.02	0.2875	4.117	0.791
50	matched	7.051	0.24	7.416	0.753
75	matched	9.835	0.2495	7.517	0.7625
100	matched	11.36	0.2495	6.753	0.7625
125	matched	12.33	0.259	5.92	0.772
150	matched	12.96	0.2685	5.15	0.7815
200	matched	9.182	0.2875	4.141	0.791
50	S. C.	10.2	0.2305	7.722	0.753
75	S. C.	11.86	0.2495	7.751	0.7625
100	S. C.	12.99	0.24	6.892	0.772
125	S. C.	11.98	0.259	6.02	0.772
150	S. C.	12.87	0.2685	5.217	0.7815
200	S. C.	8.849	0.2875	4.152	0.791

Figure 10. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

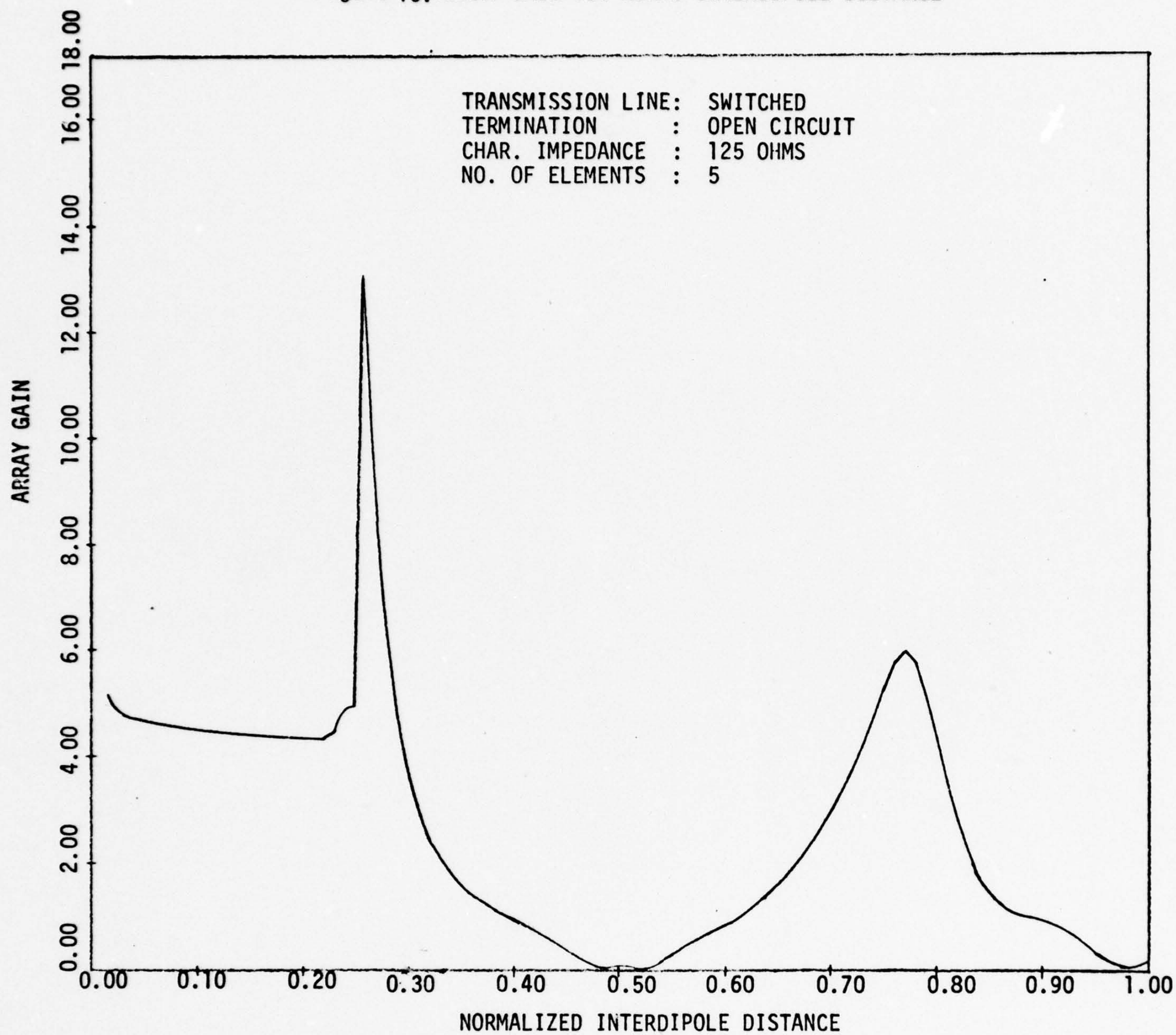


Figure 11. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE

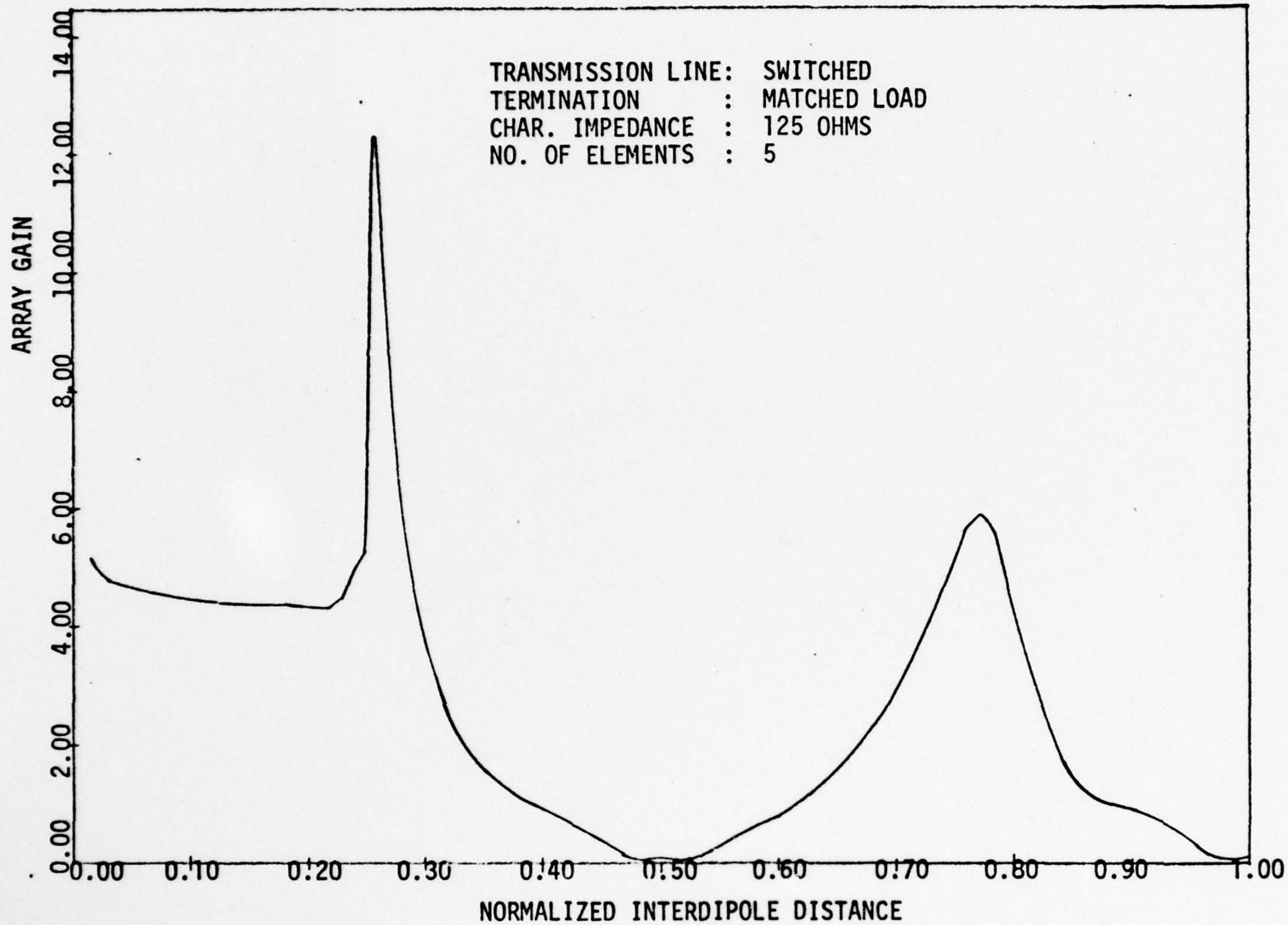
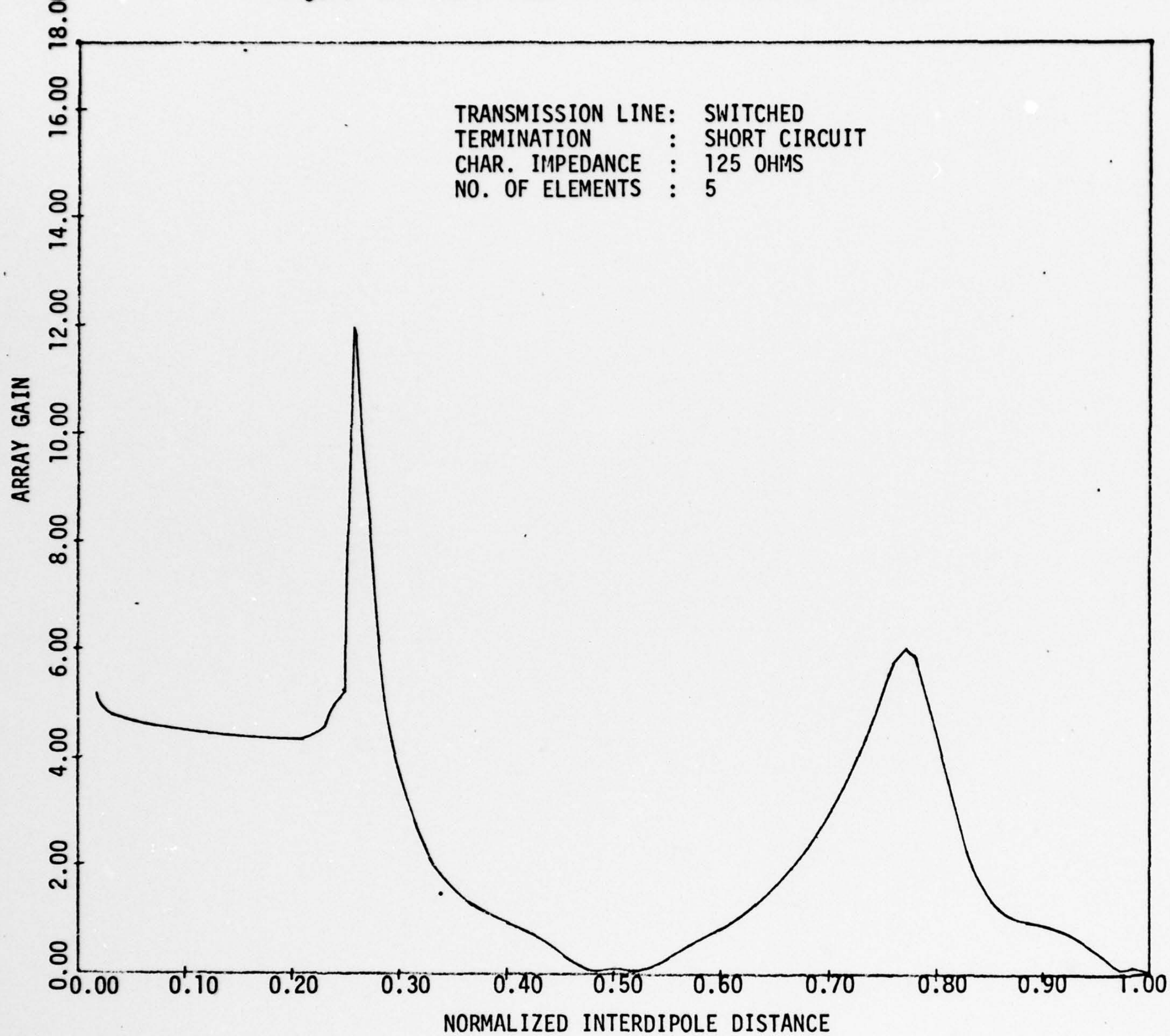


Figure 12. ARRAY GAIN VS. NORM. INTERDIPOLE DISTANCE



The conclusions drawn from Table 1 are also generally true for this case.

V. ARRAY GAIN MAXIMIZATION WITH RESPECT TO UNIFORM INTERDIPOLE SPACING

Gain vs. normalized interdipole spacing curves shown in the previous section have generally two principal gain maxima in each case. These curves are based on gain calculations made for the normalized interdipole spacing in increments of 0.0095λ. It is, therefore, possible to miss the actual maximum. A maximization program was coupled to the antenna gain calculation program to achieve this purpose. The following Table shows the maximum gain and the corresponding interdipole distance near the first principal maximum for the three-dipole array. These data agree well with that presented in the previous section. Similar data were also obtained for the four- and five- dipole array, but are not presented here.

Table 4

Array Gain Maximization with Respect to Uniform Interdipole Spacing

Z_C (Ω)	Z_T	Optimum Uniform Dipole Spacing (Norm.) d/λ	Array Gain G
50	O. C.	0.22	3.718
75	O. C.	0.2206	6.508
100	O. C.	0.2413	8.312
125	O. C.	0.2563	8.791
150	O. C.	0.2681	8.301
200	O. C.	0.2881	6.88
50	matched	0.1975	4.468
75	matched	0.23	6.509
100	matched	0.2469	7.78
125	matched	0.2588	8.089
150	matched	0.2688	7.736
200	matched	0.2875	6.687
50	S. C.	0.215	7.158
75	S. C.	0.235	8.713
100	S. C.	0.2494	9.231
125	S. C.	0.2613	8.814
150	S. C.	0.2713	7.96
200	S. C.	0.29	6.503

VI. ARRAY GAIN MAXIMIZATION AS A FUNCTION OF DIPOLE LENGTHS AND INTERDIPOLE DISTANCE

In this study both dipole lengths and interdipole distances were independently varied to obtain maximum array gain for different cases of transmission line characteristic impedances and terminations. The data obtained for the three-, four- and five-dipole arrays are given in the following tables. Symbols used in the following tables are

H_1/λ = normalized half-length of the first dipole located at the generator end

H_2/λ = normalized half-length of the dipole next to the first dipole

etc.

d_1/λ = normalized distance between the first and the second pole

d_2/λ = normalized distance between the second and third dipole

etc.

G_{max} = maximum array gain

Table 5

Gain Maximization for the Three-Dipole Array

Z_C (Ω)	Z_T	d_1/λ	d_2/λ	H_1/λ	H_2/λ	H_3/λ	G_{max}
50	O. C.	0.168	0.1928	0.2368	0.2379	0.3266	10.42
75	O. C.	0.173	0.1992	0.2466	0.2393	0.3444	10.35
100	O. C.	0.1511	0.212	0.2631	0.2388	0.3705	10.37
125	O. C.	0.1552	0.2213	0.2786	0.2393	0.3611	10.26
150	O. C.	0.1778	0.2157	0.2884	0.2419	0.371	10.23
200	O. C.	0.2014	0.217	0.317	0.2456	0.3759	10.11
50	matched	0.2733	0.2199	0.244	0.2285	0.2353	8.967
75	matched	0.2651	0.2482	0.2506	0.2346	0.2338	9.038
100	matched	0.26	0.2574	0.2587	0.2421	0.2345	9.064
125	matched	0.2596	0.2659	0.2633	0.2507	0.2332	9.062
150	matched	0.266	0.2557	0.2702	0.2603	0.2348	9.06
200	matched	0.2515	0.2655	0.2803	0.2789	0.2359	9.067
50	S. C.	0.1064	0.3178	0.2378	0.2409	0.3606	10.07
75	S. C.	0.1143	0.3152	0.244	0.2425	0.3764	9.997
100	S. C.	0.2448	0.2519	0.2496	0.2494	0.2541	9.267
125	S. C.	0.1749	0.2649	0.2457	0.2671	0.3899	9.522
150	S. C.	0.1	0.3258	0.2712	0.2449	0.4213	10.12
200	S. C.	0.2038	0.2394	0.2576	0.2917	0.3981	9.448

Table 6

Gain Maximization for the Four-Dipole Array

$Z_C(\Omega)$	Z_T	d_1/λ	d_2/λ	d_3/λ	H_1/λ	H_2/λ	H_3/λ	H_4/λ	G_{max}
50	O. C.	0.2461	0.2475	0.1777	0.241	0.2331	0.2358	0.2748	16.44
75	O. C.	0.2641	0.2451	0.2171	0.249	0.2415	0.2351	0.2695	15.91
100	O. C.	0.2558	0.2567	0.244	0.2535	0.2469	0.2389	0.2548	15.66
125	O. C.	0.243	0.2518	0.2047	0.2672	0.2486	0.2457	0.3008	16.03
150	O. C.	0.2593	0.2574	0.2488	0.2707	0.2592	0.2452	0.2754	15.66
200	O. C.	0.2675	0.2451	0.2566	0.2767	0.2753	0.2492	0.2915	15.6
50	matched	0.2517	0.2551	0.2534	0.2422	0.2342	0.2298	0.2367	14.84
75	matched	0.2516	0.2594	0.2599	0.2454	0.2408	0.2352	0.236	15.15
100	matched	0.2298	0.269	0.2676	0.2622	0.2436	0.2408	0.2363	15.34
125	matched	0.2377	0.2618	0.2825	0.2704	0.2489	0.2455	0.2355	15.27
150	matched	0.2293	0.2627	0.2841	0.2835	0.2527	0.2522	0.2355	15.28
200	matched	0.2471	0.2565	0.2626	0.2651	0.272	0.2631	0.2447	14.4
50	S. C.	0.23	0.2333	0.2504	0.255	0.2315	0.2357	0.2555	16.04
75	S. C.	0.2284	0.247	0.2525	0.2618	0.2364	0.2407	0.2568	15.84
100	S. C.	0.2335	0.2491	0.2617	0.2694	0.2417	0.2453	0.2562	15.62
125	S. C.	0.2096	0.2429	0.2395	0.289	0.2428	0.2614	0.2965	15.81
150	S. C.	0.2492	0.2487	0.2907	0.2807	0.2532	0.2513	0.2441	15.15
200	S. C.	0.2383	0.2506	0.2745	0.3067	0.2567	0.2671	0.2667	15.21

Table 7

Gain Maximization for the Five-Dipole Array

Z_C (Ω)	Z_T	d_1/λ	d_2/λ	d_3/λ	d_4/λ	H_1/λ	H_2/λ	H_3/λ	H_4/λ	H_5/λ	G_{max}
50	O. C.	0.2493	0.258	0.25	0.2309	0.2295	0.2353	0.2351	0.2316	0.2434	22.94
75	O. C.	0.2405	0.2531	0.2585	0.225	0.2478	0.2418	0.239	0.2362	0.2571	24.07
100	O. C.	0.2453	0.2567	0.2629	0.2506	0.2527	0.2466	0.2428	0.2391	0.2533	23.62
125	O. C.	0.2346	0.2609	0.2611	0.2703	0.2671	0.2517	0.2472	0.2428	0.2499	23.63
150	O. C.	0.2041	0.2717	0.2596	0.2811	0.3077	0.2517	0.2517	0.247	0.2475	23.45
200	O. C.	0.2731	0.2356	0.2873	0.2339	0.2671	0.2769	0.2555	0.2523	0.2959	23.39
50	matched	0.2462	0.2515	0.2566	0.2256	0.2333	0.235	0.2354	0.2321	0.2408	22.54
75	matched	0.2326	0.2507	0.2642	0.2542	0.2577	0.2401	0.239	0.2361	0.2384	23.54
100	matched	0.2324	0.2519	0.2712	0.2587	0.2696	0.244	0.2436	0.2394	0.2393	23.37
125	matched	0.2387	0.2553	0.2655	0.2839	0.272	0.2522	0.2464	0.2437	0.2384	23.31
150	matched	0.2524	0.2658	0.2685	0.2685	0.265	0.25	0.25	0.25	0.245	20.43 *
200	matched	0.2076	0.2731	0.2099	0.5303	0.2537	0.2928	0.2711	0.2414	0.148	13.61 *
50	S. C.	0.2489	0.2558	0.2456	0.2351	0.2372	0.2348	0.2334	0.2345	0.2497	24.34
75	S. C.	0.2497	0.2476	0.2461	0.2371	0.2543	0.2424	0.2368	0.2431	0.2655	24.35
100	S. C.	0.2515	0.2486	0.2547	0.2569	0.2597	0.2498	0.2409	0.2444	0.2588	23.71
125	S. C.	0.2328	0.2563	0.2578	0.2481	0.2844	0.2497	0.2457	0.2508	0.2672	23.47
150	S. C.	0.2317	0.2618	0.2578	0.2826	0.2825	0.2575	0.25	0.25	0.2497	23.21
200	S. C.	0.2547	0.2655	0.2595	0.1	0.264	0.2742	0.2493	0.2602	0.0966	15.07 *

The star marked pieces of data should be disregarded since it appears that the maximization process reached a smaller relative maximum (closer to the starting point in the maximization process) than the one sought for. This situation is true with almost any other maximization subroutine. Apart from this, the data points out to the following two important facts:

1. For a given dipole array, the maximum gain appears to be almost independent of the transmission line characteristic impedance and the type of termination used in this study.

2. The array gain is approximately given by N^2 where N is the number of dipoles in the array.

VII. ARRAY PATTERNS

Due to the lack of time E- and H-plane patterns were calculated only for the three-dipole array. The following variations of this array were studied.

a. half-wave dipoles uniformly spaced at 0.25λ

b. half-wave dipoles uniformly spaced at optimum uniform spacing

c. dipoles of optimum length spaced at optimum separation to yield maximum gain.

Analysis of data shows that, except for one isolated case, the mean beam was always pointing in the end-fire direction. Both E- and H- patterns showed several maxima and minima. The data on the beam width (BW) front-to-back ratio (FRB) and array gain for the different configurations are summarized in the following table.

Table 8

E - and H - Plane Patterns for the Three-Dipole Array

Type of Array	Z_C	Z_T	BW_E	BW_H	FRB	G
a	50 Ω	O. C.	70.31°	120.31°	1.3	3.609
b	50 Ω	O. C.	59.96°	91.22°	1.06	3.718
c	50 Ω	O. C.	52.35°	66.78°	2.76	10.42
a	75 Ω	O. C.	65.12°	106.36°	1.68	4.687
b	75 Ω	O. C.	50.64°	65.34°	1.89	6.508
c	75 Ω	O. C.	52.51°	67.1°	2.78	10.35
a	100Ω	O. C.	57.2°	81.4°	2.69	7.417
b	100Ω	O. C.	53.33°	71.34°	2.88	8.312
c	100Ω	O. C.	52.3°	66.32°	3.45	10.37
a	125Ω	O. C.	54.36°	74.07°	3.04	8.13
b	125Ω	O. C.	55.6°	76.85°	3.52	8.791
c	125Ω	O. C.	51.74°	65.13°	3.35	10.26
a	150Ω	O. C.	58.62°	91.35°	2.06	5.181
b	150Ω	O. C.	57.61°	82.25°	3.47	8.301
c	150Ω	O. C.	52.04°	66.27°	3.13	10.23
a	200Ω	O. C.	70.19°	182.61°	1.51	3.11
b	200Ω	O. C.	60.52°	91.4°	2.73	6.88
c	200Ω	O. C.	51.95°	67.08°	3.13	10.11
a	50 Ω	matched	62.44°	99.55°	4.13	3.215
b	50 Ω	matched	54.28°	74.56°	39.06	4.468
c	50 Ω	matched	53.53°	70.19°	2.36	8.967
a	75 Ω	matched	58.83°	86.44°	6.39	5.447
b	75 Ω	matched	54.49°	74.31°	8.77	6.509
c	75 Ω	matched	53.9°	71.43°	2.27	9.038
a	100Ω	matched	56.41°	79.03°	5.66	7.716
b	100Ω	matched	55.8°	77.46°	5.35	7.78
c	100Ω	matched	53.55°	71.18°	2.18	9.064
a	125Ω	matched	56.41°	79.66°	3.46	7.348
b	125Ω	matched	57.41°	81.71°	4.33	8.09
c	125Ω	matched	53.63°	71.98°	2.11	9.062
a	150Ω	matched	58.89°	90.57°	2.44	5.38
b	150Ω	matched	58.94°	86.1°	3.78	7.736
c	150Ω	matched	52.85°	70.99°	1.98	9.06

Table 8 Continued

Type of Array	Z_C	Z_T	BW_E	BW_H	FRB	G
a	200Ω	matched	67.63°	190.03°	1.69	3.183
b	200Ω	matched	61.29°	93.65°	3.02	6.687
c	200Ω	matched	51.93°	70.46°	1.93	9.067
a	50 Ω	S. C.	69.16°	148.69°	.91	3.018
b	50 Ω	S. C.	47.66°	59.34°	1.28	7.158
c	50 Ω	S. C.	52.45°	69.92°	2.63	10.07
a	75 Ω	S. C.	55.68°	79.77°	1.24	5.895
b	75 Ω	S. C.	50.00°	63.99°	1.52	8.713
c	75 Ω	S. C.	52.54°	70.19°	2.54	9.997
a	100Ω	S. C.	53.04°	70.73°	1.88	9.227
b	100Ω	S. C.	52.94°	70.5°	1.89	9.231
c	100Ω	S. C.	53.24°	71.17°	1.93	9.267
a	125Ω	S. C.	55.77°	78.4°	2.28	7.239
b	125Ω	S. C.	56.04°	78.16°	2.36	8.814
c	125Ω	S. C.	51.45°	68.02°	1.87	9.522
a	150Ω	S. C.	59.96°	95.63°	2.13	5.148
b	150Ω	S. C.	58.6°	85.3	2.74	7.96
c	150Ω	S. C.	51.22°	68.37°	3.11	10.12
a	200Ω	S. C.	67.59°	173.16°	1.71	3.358
b	200Ω	S. C.	62.07°	96.56°	2.66	6.503
c	200Ω	S. C.	50.42°	67.32°	1.77	9.448

Three important observations may be made from the above data.

1. For each combination of Z_C and Z_T the E- and H-plane beam widths corresponding to the optimum array c (where both dipole lengths and spacings are optimized to obtain maximum gain) are generally the smallest among these values related to the three types (a, b, c) of arrays.

2. For each type of termination Z_T, the E- and H- plane beam widths corresponding to the optimum array c are practically independent of Z_C.

3. Beam widths corresponding to the optimum array are not significantly different for the three types of terminations either.

VIII. CONCLUSIONS

This investigation pertains to an array of three or more dipoles located on a transmission line. Numerical computations for the array gain and patterns have been made for six different transmission line characteristic impedances and three types of terminations. The results of this investigation are summarized below.

When the dipole lengths are held constant (half-wavelength long in this work) the array gain is found to vary with the uniform interdipole distance. Normally two principal maxima exist for all cases investigated. However, for an array of odd number of dipoles a secondary maximum is present for $d/\lambda \approx 0.5$, and a null is found at the same ($d/\lambda \simeq 0.5$) value for an array with even number of dipoles. Generally the gain at the first principal maximum (corresponding to the shorter interdipole distance) is higher than that for the second principal maximum. In the neighborhood of the first principal maximum the gain changes rapidly with spacing, the more so with larger number of dipoles. It is interesting to note that the uniform dipole separation corresponding to each of the two principal gain maxima is more or less independent of the three types of the terminations used. For each type of termination the array gain is a function of the transmission line characteristic impedance and attains a maximum value (around 125 ohms in this investigation).

When the array gain is maximized by changing the dipole lengths and separations independently, the maximum gain appears to be independent of the transmission line characteristic impedance and the termination used,

and it is approximately equal to N^2, where N is the number of dipoles in the array.

The main beam is found to be in the end-fire direction. The E- and H-plane beam widths for the optimum array (where the dipole lengths and spacings are independently varied to attain maximum array gain) are found to be practically independent of the characteristic impedance of the transmission line and its termination.

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Gain and pattern calculations have been made for an end-fire array of dipoles on a transmission line. For uniform dipole separation it is found that the array gain is a function of the line characteristic impedance and it attains a maximum value for a certain characteristic impedance. Two principal gain maxima are found to exist and the first one corresponding to a shorter uniform interdipole distance has a higher value and it is generally sharper than the other. An array with even number of dipoles has zero gain

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for the uniform interdipole distance of about half a wavelength. On the other hand, arrays with odd number of dipoles show a small relative maximum at the same interdipole distance. For a given line, the uniform dipole separation corresponding to the gain maxima appears to be independent of the termination.

When the end-fire array gain is maximized by varying the interdipole distances and individual dipole lengths, the maximum array gain and the beam width seem to be more or less independent of the transmission line impedance and the termination. The maximum array gain is about N^2, where N is the number of dipoles in the array.

N squared

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